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(54) BIOACTIVE AND BIODEGRADABLE COMPOSITES OF POLYMERS AND CERAMICS OR GLASSES AND METHOD TO MANUFACTURE SUCH COMPOSITES

BIOAKTIVES UND BIOLOGISCH ABBAUBARES VERBUNDMATERIAL AUF DER BASIS VON POLYMEREN UND KERAMIKEN ODER GLÄSER UND VERFAHREN ZU SEINER HERSTELLUNG

COMPOSITES BIOACTIFS ET BIODEGRADABLES DE POLYMERES ET DE CERAMIQUES OU DE VERRES ET PROCEDES SERVANT A LES FABRIQUER

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Description

Field of the Invention

[0001] The present invention relates to a surgical osteosynthesis composite material, which is biodegradable and bioactive, and methods of manufacturing the composite material.

Background of the Invention

[0002] In surgery, either biostable or biodegradable devices are used for the fixation of bone fractures to immobilize the bone fragments and accelerate patient mobilization.

[0003] Most biostable devices are typically made of metallic alloys. *See* R.M. Pilliar, Powder Metal-Made Orthopaedic Implants With Porous Surface For Fixation By Tissue Ingrowth, Clinical Orthopaedics and Related Research, Vol. 176, 1983, pp. 42-51. Nevertheless, there are several disadvantages in the use of metallic implants. One such disadvantage is bone resorption caused by bone plates and screws, which carry most of the external loads, leading to stress protection produced by the modulus mismatch between metals and bone. Another disadvantage is the carcinogenic potential and the possibility of corrosion. Therefore, surgeons are recommended to remove metallic bone plates and screws in a second operation once the fracture has healed.

[0004] Bioresorbable polymeric fracture fixation devices have been studied as replacements for metallic implants. *See* S. Vainiopää, P. Rokkanen, P. Törmälä, Surgical Applications Of Biodegradable Polymers In Human Tissue, Progress in Polymer Science, Vol. 14, 1989, pp. 679-716. The advantages of these devices are that materials resorb in the body and degradation products disappear via metabolic routes. Hence, a second operation is not required. Additionally, the strength and the stiffness of the bioresorbable polymeric devices decreases when the device degrades and hence the bone is progressively loaded (which promotes bone regeneration). One disadvantage is the relatively low strength of existing polymeric devices. In the case of cortical, bone fracture, for example, unreinforced poly lactic acid (PLLA) plate and screws are too weak initially to permit patient mobilization. *See* J. Eitenmüller, K.L. Geriach,T. Schmickal, H. Krause, An In Vivo Evaluation Of A New High Molecular Weight Polylactide Osteosynthesis Device, European Congress on Biomaterials, Bologna Italy, September 14-17, 1986, p. 94. In addition, the relatively low values of Young's modulus compared to metallic plates mean that thicker sections are required to ensure adequate stability.

[0005] Törmälä et al. have developed self-reinforced bioresorbable polymeric composites to improve the strength of bioresorbable polymer devices. These show good mechanical properties: e.g. bending strengths of 360±70 MPa and bending moduli of 12±2 GPa, respectively, have been reported. *See* P. Törmälä, Biodegradable Self-Reinforced Composite Materials; Manufacturing, Structure and Mechanical Properties, Clinical Materials, Vol. 10, 1992, pp. 29-34,

[0006] A common property of most polymeric implants is the lack of bony ongrowth to the material. In contrast, such bone apposition is produced by bioactive ceramics and glasses. *See* O.H. Andersson, K.H. Karlsson, Bioactive Glass, Biomaterials Today And Tomorrow, Proceedings of the Finnish Dental Society Days of Research, Tampere, Finland, 10-11 November 1995, Gillot Oy, Turku, 1996, pp. 15-16. By adding bioactive ceramics or glasses to polymers to produce a composite, the bioactivity of the material can be improved. This effect has been demonstrated in dental composites and bone cement. *See* J.C. Behiri, M. Braden, S.N. Khorashani, D. Wiwattanadate, W. Bonfield, Advanced Bone Cement For Long Term Orthopaedic Applications, Bioceramics; Vol. 4, ed. W. Bonfield, G.W. Hastings and K.E. Tanner, Butterworth-Heinemann ltd, Oxford, 1991, pp. 301-307.

[0007] Bonfield et al have developed a biostable composite consisting of a polyethylene matrix and a particulate hydroxyapatite reinforcement (HAPEX™). *See* W, Bonfield, J.A. Bowman, M.D. Grynpas, UK Patent GB2085461, 1984. HAPEX™ composites show bioactivity above 0.20 volume fraction hydroxyapatite. *See* W. Bonfield, C. Doyle, K.E. Tanner, In Vivo Evaluation Of Hydroxyapatite Reinforced Polyethylene Composites, Biological and Biomechanical Properties of Biomaterials, ed., P. Crystel, A. Meunter, A.J.C. Lee, Elsevier Science Publisher, 1986, pp. 153-158. Additionally, degradable composites of hydroxyapatite and copolymers of polyhydroxybutyrate and polyhydroxyvalerate have been described. *See* C. Doyle, K.E. Tanner, W. Bonfield, In Vitro And In Vivo Evaluation Of Polyhydroxybutyrate And Of Polyhydroxyvalerate Reinforced With Hydroxyapatite, Biomaterials, Vol. 12, 1991, pp. 841-847. The main limitation of these biostable and biodegradable composites is their inadequate mechanical strength for large bone fracture fixation. Also, use of hydroxyapatite and poly lactic acid composites has been reported. *See* Y. Ikada, H.H. Suong, Y. Shimizu, S. Watanabe, T. Nakamura, M. Suzuki, A.T. Shimamoto, Osteosynthetic Pin, U.S. Patent 4,898,186, 1990. Using existing elements the composite still has quite moderate mechanical strength. Also in all these cases mentioned above the method of producing the composite differs from the method of the present invention.

Summary of the Invention

[0008] In this invention, we have established that the problems of inadequate strength and the brittleness of the

bioactive bone fixation devices and the lack of bioactivity of absorbable polymeric devices are resolved by constructing a composite material comprising at least one resorbable polymeric matrix, at least one bioactive ceramic reinforcing element and at least one resorbable polymeric reinforcing component. The composite material described in more detail herein consists of two reinforcing components in a matrix material. One reinforcing element, the polymeric reinforcing element, is comprised of biodegradable polymer fiber and the other, called the ceramic reinforcing element, is comprised of bioceramic or bioglass. Reinforced composite devices described in this invention have improved mechanical properties compared to non-reinforced devices, because reinforcement changes the behavior of material from brittle to ductile and thus makes device more reliable under load. Due to controlled manufacturing stages, mixing of matrix and ceramic reinforcing element as well as combining the polymeric reinforcing element, the amount of both reinforcing element types is easily controlled. This is an important advantage, because the ratio of elements affects the mechanical properties of the device. Also, the amount of the ceramic reinforcing element affects the bioactivity of the device.

Brief Description of the Drawings

[0009]

Figure 1 Shows a schematic picture of the cross-section of a composite plate of the invention.
Figure 2a Shows a FTIR spectrum of hydroxyapatite,
Figure 2b Shows a FTIR spectrum of hydroxyapatite-poly lactic acid composite, and
Figure 2c Shows a FTIR spectrum of poly lactic acid composite.

Description of the Preferred Embodiments

[0010] This invention relates to biodegradable materials used for bone fracture fixation devices and methods of their manufacture. Unlike other known materials used prior to this application, the composites of this invention have two different reinforcing phases and one matrix phase. One reinforcing element is referred as the polymeric reinforcing element and the other as the ceramic reinforcing element. The matrix component can be any biodegradable or bioerodible polymer. Typical examples of these polymers are listed in Table 1 herein.

[0011] One reinforcing phase is a totally or at least partially oriented and/or fibrillated biodegradable or bioerodible polymer. This phase is called the polymeric reinforcing element, which is still recognizable and distinguishable from the final product as a whole. The diameter of the reinforcing fibers can vary between 4 μm and 800 μm, preferably between 20 μm and 500 μm. Useful polymers for the polymeric reinforcing element include those listed in Table 1.

[0012] The ceramic reinforcing element can be comprised of a stable or a degradable bioceramic or bioglass, or a mixture of these. Typical examples are listed in Table 2. They can be used in a powder, flake, spherical, fiber or any other form. Particle size can vary between 2 μm and 100 μm, preferably between 60 μm and 150 μm. In the case of fibers, the fibers are in all cases smaller than the polymeric reinforcing elements. The ceramic reinforcing element also acts as a bioactive, bony ongrowth agent and provides a reservoir of calcium and phosphate ions, thus accelerating the healing time for bone fractures. While the matrix polymer degrades, bone can attach to the residual ceramic or glass particles. The amount of ceramic reinforcing element is 0.15 to 0.9 volume fraction, preferably between 0.2 and 0.6 volume fraction.

[0013] The defined particle size of the ceramic element in the composite described in this invention is relatively big compared to conventionally used particle sizes for fillers or granules. In this invention, it was found unexpectedly that composites having bigger particle size ceramic elements are more biocompatible and cause less irritation to tissue than composites utilizing a ceramic element having small particle size. Biocompatibility is easily seen in histological studies. In tissue near and inside the degrading composite implants having small ceramic particles there exists more giant cells than around and inside the degrading composite implants containing big (coarser) ceramic particles.

[0014] The invention may contain various additives and modifiers which improve the processability of the composite. Such additives include surface modifiers to improve the attachment between the polymeric and ceramic components. The devices can also contain pharmaceutically active agent or agents, such as antibiotics, chemotherapeutic agents, wound-healing agents, growth hormones and anticoagulants (such as heparin). These agents are used to enhance the bioactive feature of the composite and thus improve the healing process of the tissue.

[0015] Manufacture of the composite can be performed by any suitable plastics technology processing method. The matrix polymer and the ceramic reinforcing element(s) (bioceramic or bioglass) can be mixed together by powder mixing, melt mixing or solvent mixing. The polymeric reinforcing element (polymer fiber) can be used as plain fiber or in modified form: for example, as braided or woven two or three dimensional structures. The mixture of matrix and the ceramic reinforcing element can be combined with the polymeric reinforcing element by melt mixing, by coating or by using solvent as an intermediate to preform the material (prepreg). The material can be produced in its final form by various techniques, including compression molding, filament winding, mechanical machining or injection molding to

any desired shape.

[0016] Due to controlled manufacturing stages, mixing of matrix and ceramic reinforcing element as well as combining the polymeric reinforcing element, the amount of both reinforcing element types is easily controlled. This is an important advantage, because the ratio of elements affects the mechanical properties of the device. Also, the amount of the ceramic reinforcing element affects the bioactivity of the device. There should be sufficient bioceramic or bioglass to yield bony ongrowth.

[0017] Reinforced composite devices described in this invention have improved mechanical properties compared to non-reinforced devices, because reinforcement changes the behavior of the material from brittle to ductile and thus makes the reinforced device more reliable under load. This feature is very important for load bearing applications, such as bone fracture fixation devices. For example, non-reinforced poly lactic acid devices typically have three-point bending strengths of 35-40 MPa and moduli of 3.5-4.0 GPa, and particulate reinforced (hydroxyapatite) poly lactic acid devices have values of 25-30 MPa and 5.0 GPa, respectively. Using polymer fiber reinforcement under the present invention, mechanical properties of two to five times higher are achieved.

EXAMPLES

[0018] The present invention is described in more detail by means of the following, non-limiting examples.

Example 1.

[0019] Plates sized approximately 50 x 10 x 2 mm were manufactured by compression molding from a powder mixture of poly (L,D-lactide) (95/5 L/D ratio) and hydroxyapatite with particle size of 60 µm, reinforced unidirectionally with poly (L-lactide) fibers (53/35/12 weight percent of matrix polymer-hydroxyapatite-polymer fiber, respectively). Three-point bending strength (yield) and modulus were 69.8 MPa and 5.8 GPa, respectively, and no sample fracture was detected (ductile behavior). These results were compared to the results of similarly sized samples without fiber reinforcement, compression molded from (1) plain PLDLA 95/5 and from (2) powder mixture of PLDLA 95/5 and hydroxyapatite (60/40 w/w %). These samples showed three-point bending strengths (maximum) and moduli of (1): 38.0 MPa and 3.9 GPa and (2): 26.8 MPa and 5.0 GPa, respectively. These samples broke in bending without yielding, thus showing brittle fracture behavior.

Example 2.

[0020] Plates sized as in example 1 were manufactured by compression molding from a mixture of poly (L,D-lactide) (85/15 L/D ratio) and hydroxyapatite with particle size of 60 µm reinforced unidirectionally with poly (L-lactide) fibers. Poly (L,D-lactide) and hydroxyapatite were previously melt mixed to a film form. The composition had 48/21/31 weight percent of matrix polymerhydroxyapatite-polymer fibers, respectively. Three-point bending strength (yield) and modulus were 116.6 MPa and 6.1 GPa, respectively, and no sample fracture was detected.

Example 3.

[0021] Plates sized approximately 50 x 10 x 1 mm were manufactured by compression molding from the unidirectional prepreg material of poly (L,D lactide) (85/15 L/D ratio), hydroxyapatite and poly (L-lactide) fibers. The proportions of components varied from 3-16 wt-%, 15-50 wt-% and 48-85 wt-%, respectively. Three-point bending strength (yield) and modulus depended on the concentrations of the composite. Typical mechanical properties are listed in Table 3. No sample fracture was detected and the behavior was ductile.

Table 3

PLDLA (85/15) matrix (wt-%)	PLLA fibers (wt-%)	Hydroxy apatite (wt-%)	Three-point bending strength (MPa)	Three-point bending modulus (GPa)
3	82	15	136	9.5
4	71	25	143	9.1
5	47	48	141	12.2
8	61	31	139	10.5
9	54	37	118	8.3

Table 3 (continued)

PLDLA (85/15) matrix (wt-%)	PLLA fibers (wt-%)	Hydroxy apatite (wt-%)	Three-point bending strength (MPa)	Three-point bending modulus (GPa)
16	48	36	166	9.6

Example 4.

[0022] Plates sized as in example 3 were manufactured by compression molding from a prepreg material of poly (L, D-lactide) (85/15 L/D ratio), hydroxyapatite and poly (L-lactide) fibers. The proportions of components were 4 wt-%, 15 wt-% and 81 wt-%, respectively. Three sample types were manufactured having different prepreg lay-ups of 0°/0°/0°/0°/0°, 0°/45°/0°/-45°/0° and 0°/0°/90°/0°/0°. Three-point bending strengths (yield) and moduli were 135.9 MPa and 9.5 GPa, 140.1 MPa and 10.1 GPa, and 131.0 MPa and 9.3 GPa, respectively, and no sample fracture was detected.

Example 5.

[0023] The surfaces of three different samples were studied by Fourier Transform Infrared Spectroscopy. Samples were:

a) hydroxyapatite
b) hydroxyapatite-poly (D,L-lactide)-poly (L-lactide) composite
c) poly (D,L-lactide)-poly (L-lactide) composite.

[0024] The spectras from these samples are shown in figure 2. Matching peaks are detectable with samples b and c, which are poly lactide peaks. There also occur matching peaks from samples a and b which are characteristic of calcium phosphate compounds. The bioactivity of the composites claimed in this invention is the result of hydroxyapatite on the surface.

Example 6.

[0025] Plates sized as in example 3 were manufactured by compression molding from the unidirectional prepreg material of racemic poly (D,L-lactide), tricalcium phosphate with mean particle size of 70 µm and poly glycolide fibers. The proportions of components varied from 5 wt-%, 20 wt-% and 75 wt-%, respectively. Three-point bending strength (yield) and modulus were 195 MPa and 14.2 GPa, and no sample fracture was detected.

Example 7.

[0026] Plates sized as in example 3 were manufactured by compression molding from the prepreg material made of racemic poly (D,L-lactide), hydroxyapatite powder with mean particle size of 100 µm and the fabric made of poly (L-lactide) and poly (L,D lactide) (96/4) fibers. The proportions of components varied from 5 wt-%, 20 wt-% and 75 wt-%, respectively. Three-point bending strength (yield) and modulus were 150 MPa and 11.8 GPa, and no sample fracture was detected. Specimens showed similar mechanical properties in both the warp and the weft directions of the fabric.

Example 8.

[0027] Plates sized as in example 1 were manufactured by compression molding from a mixture of poly (ortho ester) and hydroxyapatite with mean particle size of 80 µm reinforced unidirectionally with poly (ortho ester) fibers. Poly (ortho ester) matrix and hydroxyapatite were previously melt mixed to a film form. The composition had 50/20/30 weight percent of matrix polymerhydroxyapatite-polymer fibers, respectively. Three-point bending strength (yield) and modulus were 105 MPa and 9.7 GPa, respectively, and no sample fracture was detected.

Example 9.

[0028] Plates sized as in example 3 were manufactured by compression molding from the unidirectional prepreg material of copolymer of poly (D,L lactide) and poly-e-caprolactone, tricalcium phosphate with mean particle size of 80 µm and poly-e-caprolactone fibers. The proportions of components varied from 16 wt-%, 30 wt-% and 54 wt-%, respectively. Three-point bending strength (yield) and modulus were 86 MPa and 3.4 GPa, and no sample fracture

was detected. The strength and modulus values were lower than those for lactide based composites, but the extension to yield was much higher.

Example 10.

[0029] Plates sized as in example 1 were manufactured by compression molding from a mixture of a copolymer of poly (hydroxybutyrate)-poly (hydroxyvalerate) and a mixture of hydroxyapatite and tricalcium phosphate (50/50) with mean particle size of 120 μm, reinforced unidirectionally with poly (hydroxybutyrate) fibers. The polymer matrix and ceramic mixture were previously melt mixed to a film form. The composition had 30/30/40 weight percent of matrix copolymer-ceramic mixture-polymer fibers, respectively. Three-point bending strength (yield) and modulus were 122 MPa and 6.2 GPa, respectively, and no sample fracture was detected.

Example 11.

[0030] Two set of samples (plates with 5 mm width, 20 mm length and 0.9 mm thickness) were implanted to the back of rats (subcurris). Specimens were made of poly-L lactic acid fibers, poly-D,L-lactic acid matrix (with L/D ratio 85/15) and hydroxyapatite powder using prepreg manufacturing method. The quantities of the components were 80 wt-%, 5 wt-% and 15 wt-%, respectively. The plates had five prepreg layers, with layer alignments of 0°/0°/0°/0°/0°. The mean particle diameter of hydroxyapatite powder in the first set of plates was 7.43 micrometers and in the second set of plates was 80±20 micrometers.. The plates were gamma sterilized with a dose of 2.5 MRads.

[0031] Five animals from both sets were sacrificed after one year of implantation. In histological studies it was clearly seen, that in and around the composite plates with finer hydroxyapatite powder there existed significantly more giant cells than in the tissue of reference animals containing composite plates with coarser hydroxyapatite particles. Thus, coarser hydroxyapatite particles were shown to be more biocompatible.

TABLE 1.

Resorbable polymers suitable for biocomposites.

Polymer
Polyglycolide (PGA)
Copolymers of glycolide:
Glycolide/L-lactide copolymers (PGA/PLLA)
Glycolide/trimethylene carbonate copolymers (PGA/TMC)
Polylactides (PLA)
Stereocopolymers of PLA:
Poly-L-lactide (PLLA)
Poly-DL-lactide (PDLLA)
L-lactide/DL-lactide copolymers
Copolymers of PLA:
Lactide/tetramethylglycolide copolymers
Lactide/trimethylene carbonate copolymers
Lactide/d-valerolactone copolymers
Lactide/e-caprolactone copolymers
PLA/polyethylene oxide copolymers
Polydepsipeptides
Unsymmetrically 3,6-substituted poly-1,4-dioxane-2,5-diones
Poly-b-hydroxybutyrate (PHB)
PHB/b-hydroxyvalerate copolymers (PHB/PHV)
Poly-b-hydroxypropionate (PHPA)
Poly-p-dioxanone (PDS)
Poly-d-valerolactone
Poly-e-caprolactone
Methylmethacrylate-N-vinyl pyrrolidone copolymers
Polyesteramides
Polyesters of oxalic acid

TABLE 1. (continued)

Resorbable polymers suitable for biocomposites.
Polydihydropyrans
Polyalkyl-2-cyanocrylates
Polyurethanes (PU)
Polyvinylalcohol (PVA)
Polypeptides
Poly-b-malic acid (PM LA)
Poly-b-alkanoic acids
Polycarbonates
Polyorthoesters
Polyphosphates

Table 2.

Bioceramics and glasses suitable for biocomposites.
Hydroxyapatite
Tricalciun phosphate
Other calcium phosphates
Bioglass®
Ceravital®
Alumina
Zirconia
Bioactive gel-glass
Bioactive glasses
Alpha wollastonite glass ceramic

Claims

1. A biodegradable and bioactive composite material for surgical osteosynthesis applications comprising: at least one resorbable polymeric matrix component, at least one resorbable polymeric reinforcing element, and at least one ceramic reinforcing element.

2. A method of manufacturing a biodegradable and bioactive composite material according to claim 1, comprising the steps of:

   a) selecting at least one first resorbable polymer for the matrix;

   b) selecting at least one bioceramic for use as the ceramic reinforcing element;

   c) mixing said first polymer and said bioceramic together to form a first mixture;

   d) selecting at least one second resorbable polymer in a fiber form for use as the polymeric reinforcing element;

   e) placing said second polymer into a desired formation;

   f) combining said first mixture of step (c) and said formation of step (e) to yield a second mixture; and

   g) subjecting the second mixture of step (f) to heat or pressure to yield the biodegradable and bioactive composite material.

3. The composite material of claim 1, **characterized in that** the ceramic reinforcing element is comprised of a stable or degradable bioceramic or bioglass.

4. The composite material of claim 3, **characterized in that** the ceramic reinforcing element has a particle size of between 2 μm and 150 μm.

5. The composite material of claim 3, **characterized in that** the ceramic reinforcing element has a particle size of between 2 μm and 100 μm.

6. The composite material of claim 3, **characterized in that** the ceramic reinforcing element has a particle size of between 60 μm and 150 μm.

7. The composite material of any of claims 2 through 6, **characterized in that** the ceramic reinforcing elements comprise between 20 percent and 60 percent, by volume, of the total composite material.

8. The composite material of any of claims 1 and 3 through 7, **characterized in that** the resorbable polymeric reinforcement element is comprised of an at least partially oriented or fibrillated biodegradable or bioerodible polymer in fiber form.

9. The composite material of claim 8, **characterized in that** the diameter of the resorbable polymeric reinforcing element is between 4 μm and 800 μm.

10. The composite material of claim 8, **characterized in that** the diameter of the resorbable polymeric reinforcing element is between 20 μm and 500 μm.

11. The composite material of any of claims 1 and 3 through 10, **characterized in that** the composite material contains at least one surface modifier.

12. The composite material of any of claims 1 and 3 through 10, **characterized in that** the composite material contains at least one pharmaceutically active agent.

13. The method of claim 2, **characterized in that** the bioceramic has a particle size of between 2 μm and 150 μm.

14. The method of claim 2, **characterized in that** the bioceramic hs a particle size of between 2μm and 100μm.

15. The method of claim 2, **characterized in that** the bioceramic has a particle size of between 60 μm and 150 μm.

16. The method of any of claims 2 and 13 through 15, **characterized in that** the bioceramic comprises between 20 percent and 60 percent, by volume, of the total biodegradable composite.

17. The method of any of claims 2 and 13 through 16, **characterized in that** the second polymer in a fiber form is comprised of an at least partially oriented or fibrillated biodegradable or bioerodible polymer.

18. The method of claim 17, **characterized in that** the diameter of the second polymer in a fiber form is between 4 μm and 800 μm.

19. The method of claim 17, **characterized in that** the diameter of the second polymer in a fiber form is between 20 μm and 500 μm.

20. The method of any of claims 2 and 13-19, further comprising the step of adding at least one surface modifier to the biodegradable composite.

21. The method of any of claims 2 and 13-19, further comprising the step of adding at least one pharmaceutically active agent to the biodegradable composite.

Patentansprüche

1. Ein bioabbaubares sowie bioaktives Kompositmaterial für chirurgische Osteosyntheseanwendungen, umfassend: wenigstens eine resorbierbare polymere Matrixkomponente, wenigstens ein resorbierbares polymeres Verstärkungselement und wenigstens ein keramisches Verstärkungselement.

2. Ein Verfahren zur Herstellung eines bioabbaubaren sowie bioaktiven Kompositmaterials nach Anspruch 1, umfassend die Schritte:

   a) Auswählen wenigstens eines ersten resorbierbaren Polymers für die Matrix;

   b) Auswählen wenigstens einer Biokeramik zur Verwendung als keramisches Verstärkungselement;

   c) Vermischen des ersten Polymers und der Biokeramik zur Bildung einer ersten Mischung;

   d) Auswählen wenigstens eines zweiten resorbierbaren Polymers in einer Faserform zur Verwendung als polymeres Verstärkungselement;

   e) Plazieren des zweiten Polymers in eine gewünschte Formung;

   f) Vereinigen der ersten Mischung von Schritt (c) und der Formung von Schritt (e), um eine zweite Mischung hervorzubringen; und

   g) Wärme- oder Druckaussetzen der zweiten Mischung von Schritt (f), um ein bioabbaubares sowie bioaktives Kompositmaterial hervorzubringen.

3. Das Kompositmaterial nach Anspruch 1, **dadurch gekennzeichnet, dass** das keramische Verstärkungselement aus einer stabilen oder abbaubaren Biokeramik oder Bioglas besteht.

4. Das Kompositmaterial nach Anspruch 3, **dadurch gekennzeichnet, dass** das keramische Verstärkungselement eine Partikelgröße zwischen 2 µm und 150 µm aufweist.

5. Das Kompositmaterial nach Anspruch 3, **dadurch gekennzeichnet, dass** das keramische Verstärkungselement eine Partikelgröße zwischen 2 µm und 100 µm aufweist.

6. Das Kompositmaterial nach Anspruch 3, **dadurch gekennzeichnet, dass** das keramische Verstärkungselement eine Partikelgröße zwischen 60 µm und 150 µm aufweist.

7. Das Kompositmaterial nach einem der Ansprüche 2 bis 6, **dadurch gekennzeichnet, dass** die keramischen Verstärkungselemente zwischen 20 und 60 Volumenprozent des gesamten Kompositmaterials umfassen.

8. Das Kompositmaterial nach einem der Ansprüche 1 und 3 bis 7, **dadurch gekennzeichnet, dass** das resorbierbare polymere Verstärkungselement aus einem wenigstens teilweise orientierten oder fibrillierten bioabbaubaren oder bioerodierbaren Polymer in Faserform besteht.

9. Das Kompositmaterial nach Anspruch 8, **dadurch gekennzeichnet, dass** der Durchmesser des resorbierbaren polymeren Verstärkungselementes zwischen 4 µm und 800 µm beträgt.

10. Das Kompositmaterial nach Anspruch 8, **dadurch gekennzeichnet, dass** der Durchmesser des resorbierbaren polymeren Verstärkungselementes zwischen 20 µm und 500 µm beträgt.

11. Das Kompositmaterial nach einem der Ansprüchen 1 und 3 bis 10, **dadurch gekennzeichnet, dass** das Kompositmaterial wenigstens ein Oberflächenmodifizierungsmittel enthält.

12. Das Kompositmaterial nach einem der Ansprüchen 1 und 3 bis 10, **dadurch gekennzeichnet, dass** das Kompositmaterial wenigstens ein pharmazeutisch aktives Agens enthält.

13. Das Verfahren nach Anspruch 2, **dadurch gekennzeichnet, dass** die Biokeramik eine Partikelgröße zwischen 2 µm und 150 µm aufweist.

14. Das Verfahren nach Anspruch 2, **dadurch gekennzeichnet, dass** die Biokeramik eine Partikelgröße zwischen 2 µm und 100 µm aufweist.

15. Das Verfahren nach Anspruch 2, **dadurch gekennzeichnet, dass** die Biokeramik eine Partikelgröße zwischen

60 µm und 150 µm aufweist.

16. Das Verfahren nach einem der Ansprüche 2 und 13 bis 15, **dadurch gekennzeichnet, dass** die Biokeramik zwischen 20 und 60 Volumenprozent des gesamten bioabbaubaren Komposits umfasst.

17. Das Verfahren nach einem der Ansprüche 2 und 13 bis 16, **dadurch gekennzeichnet, dass** das zweite Polymer in einer Faserform aus einem wenigstens teilweise orientierten oder fibrillierten bioabbaubaren oder bioerodierbaren Polymer besteht.

18. Das Verfahren nach Anspruch 17, **dadurch gekennzeichnet, dass** der Durchmesser des zweiten Polymers in einer Faserform zwischen 4 µm und 800 µm beträgt.

19. Das Verfahren nach Anspruch 17, **dadurch gekennzeichnet, dass** der Durchmesser des zweiten Polymers in einer Faserform zwischen 20 µm und 500 µm beträgt.

20. Das Verfahren nach einem der Ansprüche 2 und 13 bis 19, des weiteren umfassend den Schritt der Zugabe wenigstens eines Oberflächenmodifizierungsmittels zu dem bioabbaubaren Komposit.

21. Das Verfahren nach einem der Ansprüche 2 und 13 bis 19, des weiteren umfassend den Schritt der Zugabe wenigstens eines pharmazeutisch aktiven Agens' zu dem bioabbaubaren Komposit.

Revendications

1. Matériau composite biodégradable et bioactif pour des applications d'ostéosynthèse chirurgicale comprenant : au moins un composant matriciel polymère résorbable, au moins un élément de renfort polymère résorbable et au moins un élément de renfort céramique.

2. Méthode de fabrication d'un matériau composite biodégradable et bioactif selon la revendication 1, comprenant les étapes de

   a) sélection d'au moins un premier polymère résorbable pour la matrice ;

   b) sélection d'au moins une biocéramique à utiliser comme élément de renfort céramique ;

   c) mélange dudit premier polymère et de ladite biocéramique pour former un premier mélange ;

   d) sélection d'au moins un second polymère résorbable sous forme fibreuse à utiliser comme élément de renfort polymère ;

   e) façonnage dudit second polymère pour lui donner la forme désirée ;

   f) combinaison dudit premier mélange de l'étape c) et de ladite forme de l'étape e) pour obtenir un second mélange ; et

   g) exposition du second mélange de l'étape f) à la chaleur ou à la pression pour obtenir le matériau composite biodégradable et bioactif.

3. Matériau composite selon la revendication 1, **caractérisé en ce que** l'élément de renfort céramique se compose d'une biocéramique ou d'un bioverre stable ou dégradable.

4. Matériau composite selon la revendication 3, **caractérisé en ce que** la taille des particules de l'élément de renfort céramique est comprise entre 2 et 150 µm.

5. Matériau composite selon la revendication 3, **caractérisé en ce que** la taille des particules de l'élément de renfort céramique est comprise entre 2 et 100 µm.

6. Matériau composite selon la revendication 3, **caractérisé en ce que** la taille des particules de l'élément de renfort

céramique est comprise entre 60 et 150 μm.

7. Matériau composite selon l'une des revendications 2 à 6, **caractérisé en ce que** les éléments de renfort céramiques composent 20 à 60 % en volume du matériau composite total.

8. Matériau composite selon l'une des revendications 1 et 3 à 7, **caractérisé en ce que** l'élément de renfort polymère résorbable se compose d'un polymère biodégradable ou bioérodable, orienté au moins partiellement ou fibrillaire, sous forme fibreuse.

9. Matériau composite selon la revendication 8, **caractérisé en ce que** le diamètre de l'élément de renfort polymère résorbable est compris entre 4 et 800 μm.

10. Matériau composite selon la revendication 8, **caractérisé en ce que** le diamètre de l'élément de renfort polymère résorbable est compris entre 20 et 500 μm.

11. Matériau composite selon l'une des revendications 1 et 3 à 10, **caractérisé en ce que** le matériau composite contient au moins un modificateur de surface.

12. Matériau composite selon l'une des revendications 1 et 3 à 10, **caractérisé en ce que** le matériau composite contient au moins un agent pharmaceutiquement actif.

13. Méthode selon la revendication 2, **caractérisé en ce que** la taille des particules de la biocéramique est comprise entre 2 et 150 μm.

14. Méthode selon la revendication 2, **caractérisé en ce que** la taille des particules de la biocéramique est comprise entre 2 et 100 μm.

15. Méthode selon la revendication 2, **caractérisé en ce que** la taille des particules de la biocéramique est comprise entre 60 et 150 μm.

16. Méthode selon l'une des revendications 2 et 13 à 15, **caractérisé en ce que** la biocéramique compose 20 à 60 % en volume du matériau composite total.

17. Méthode selon l'une des revendications 2 et 13 à 16, **caractérisé en ce que** le second polymère sous forme fibreuse se compose d'un polymère biodégradable ou bioérodable, orienté au moins partiellement ou fibrillaire.

18. Méthode selon la revendication 17, **caractérisé en ce que** le diamètre du second polymère sous forme fibreuse est compris entre 4 et 800 μm.

19. Méthode selon la revendication 17, **caractérisé en ce que** le diamètre du second polymère sous forme fibreuse est compris entre 20 et 500 μm.

20. Méthode selon l'une des revendications 2 et 13 à 19, comprenant en plus l'étape consistant à additionner au moins un modificateur de surface au composite biodégradable.

21. Méthode selon l'une des revendications 2 et 13 à 19, comprenant en plus l'étape consistant à additionner au moins un agent pharmaceutiquement actif au composite biodégradable.

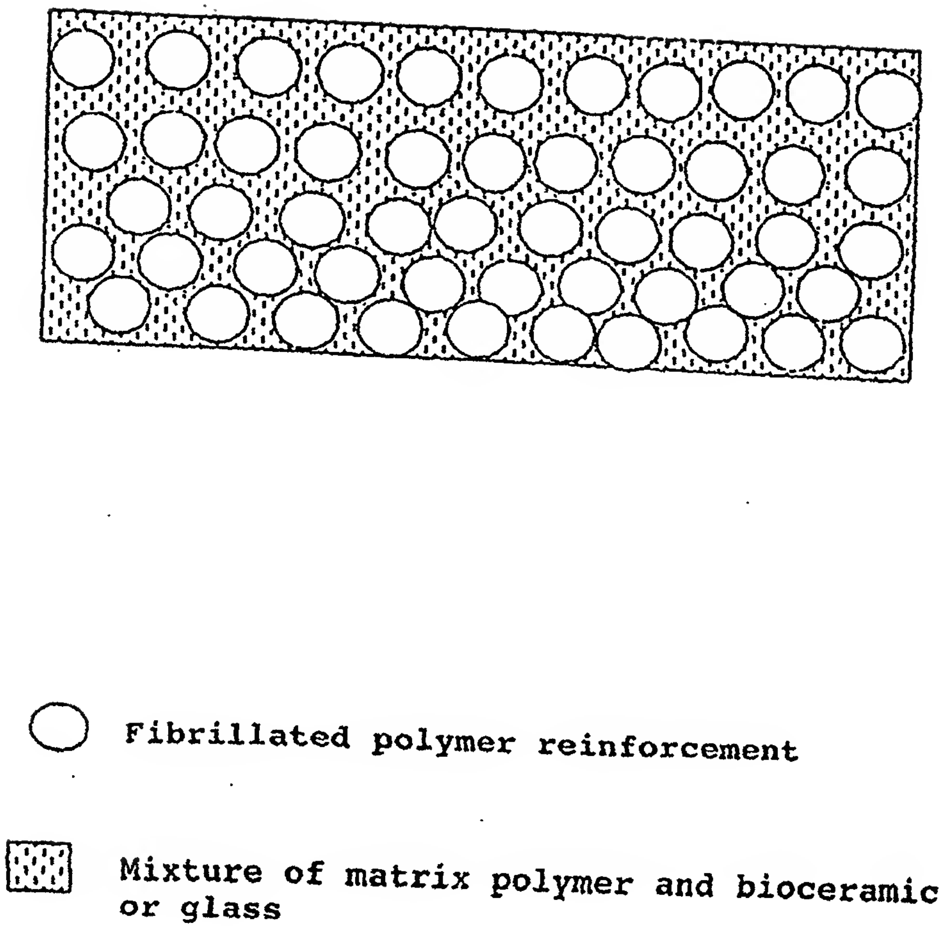
Fibrillated polymer reinforcement
Mixture of matrix polymer and bioceramic or glass

FIG.1

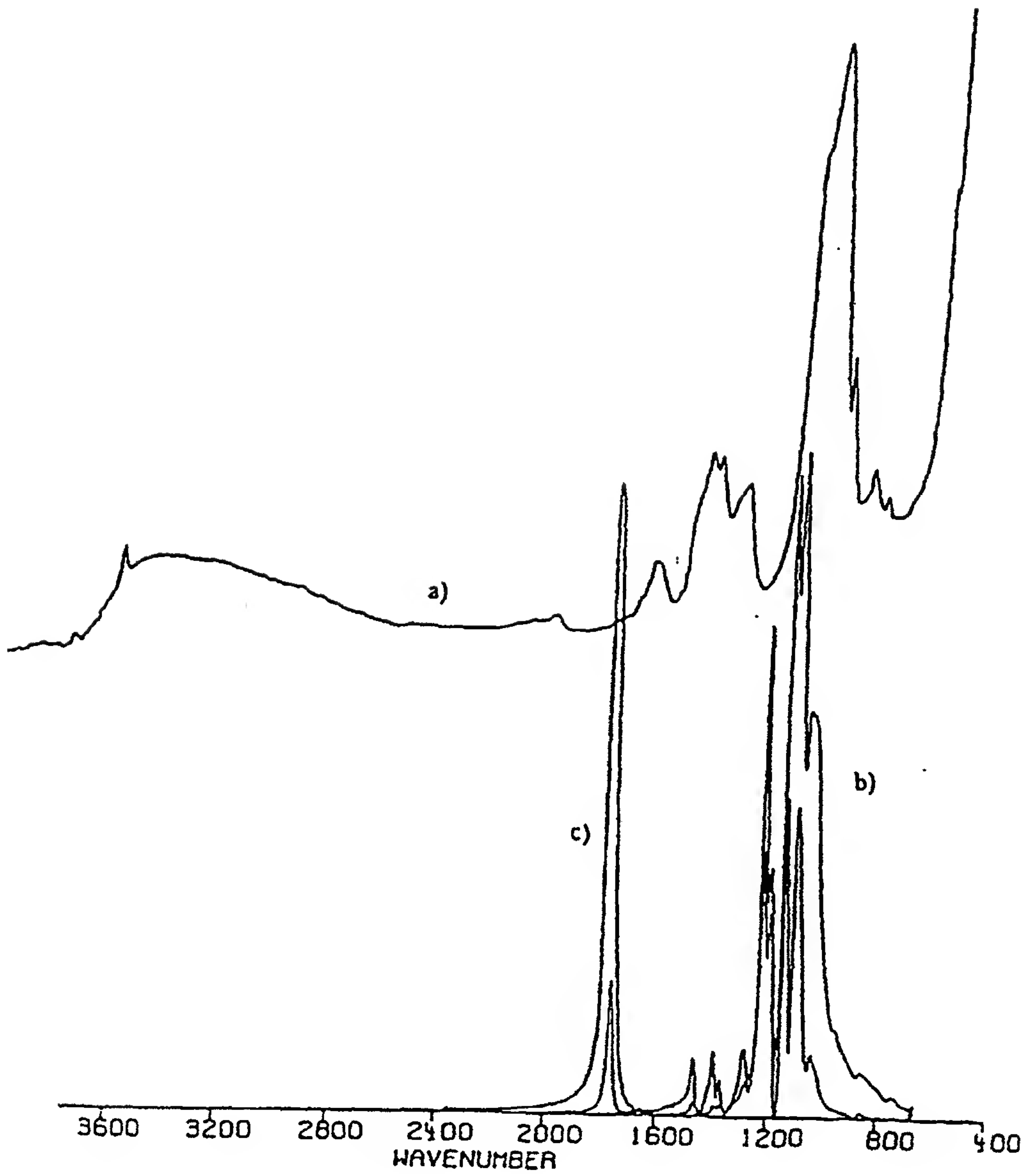

FIG.2